Predictability in Space Launch Vehicle Anomaly Detection Using Intelligent Neuro-Fuzzy Systems

JPL *JSC* *McDonnell Douglas* *Lockheed*

Joint Effort

JPL Team

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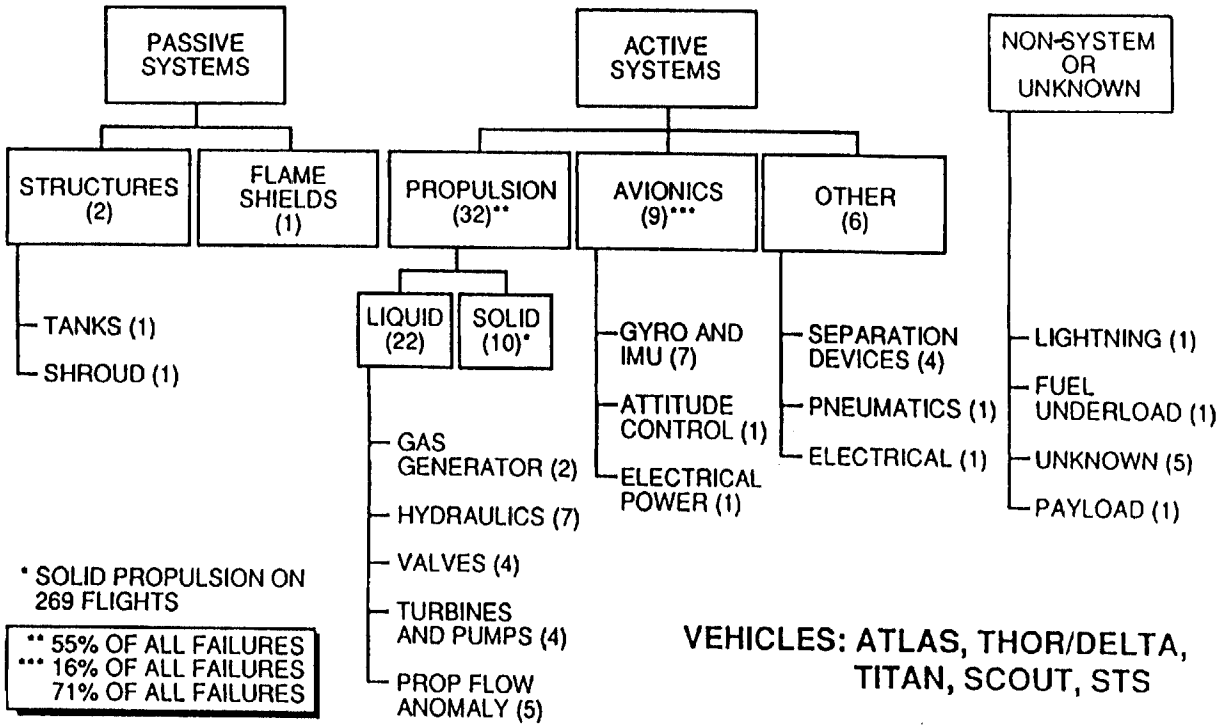
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

742 TOTAL FLIGHTS (1966-87), 58 failures



Where The Flight Failures Have Been In Launch Vehicles

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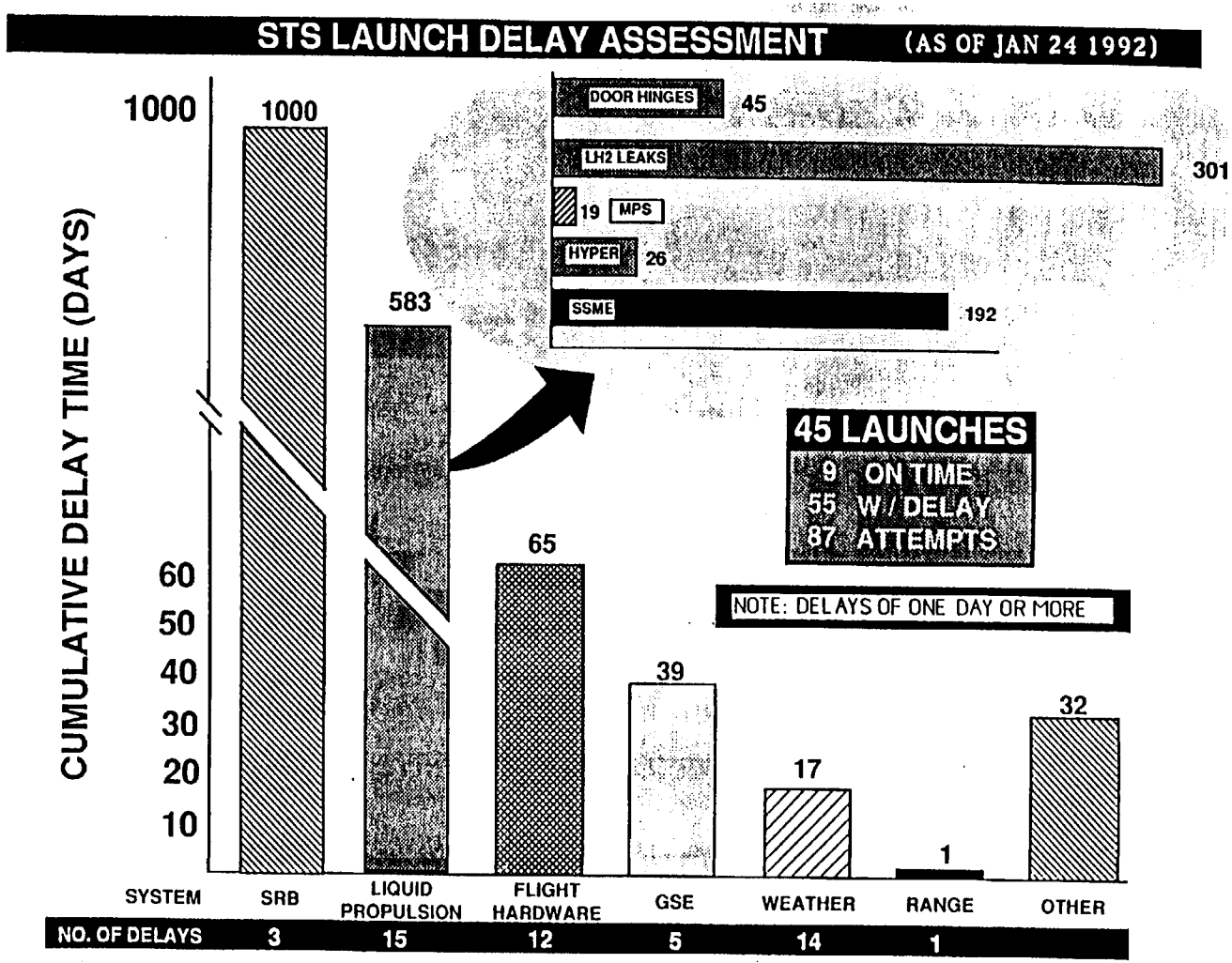
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



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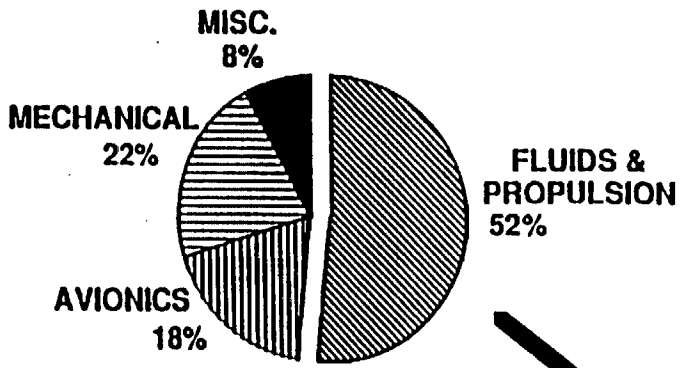
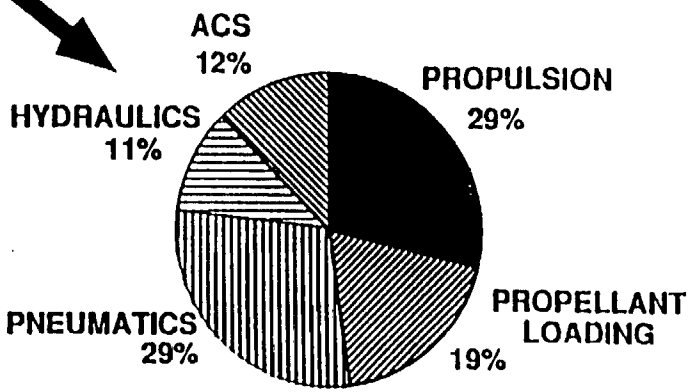
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

Breakdown of Operations Hours





FLUIDS AND PROPULSION SYSTEMS ACCOUNT FOR *HALF* OF ALL TESTING HOURS.

SPACEPORT FLORIDA INFRASTRUCTURE IMPROVEMENT STUDY

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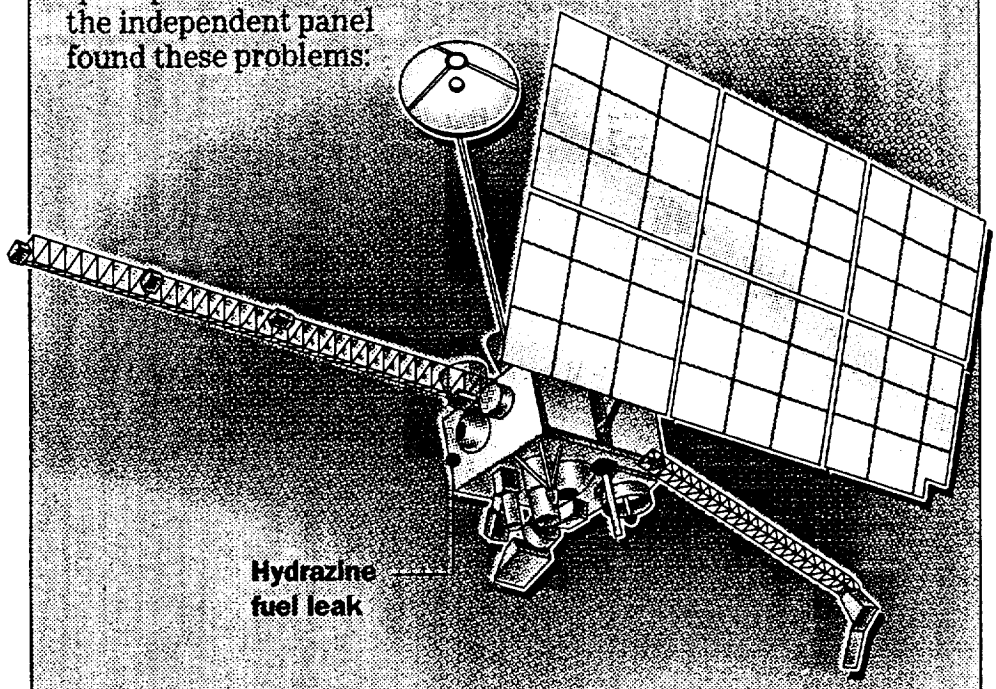
Failure of Mars Probe Blamed on Fuel Leak

Troubled Spacecraft

A federal panel Wednesday announced the findings of its inquiry into the Aug. 21 disappearance of the $980 million Mars Observer spacecraft. Exactly what happened to the space probe is not known, but the independent panel found these problems:

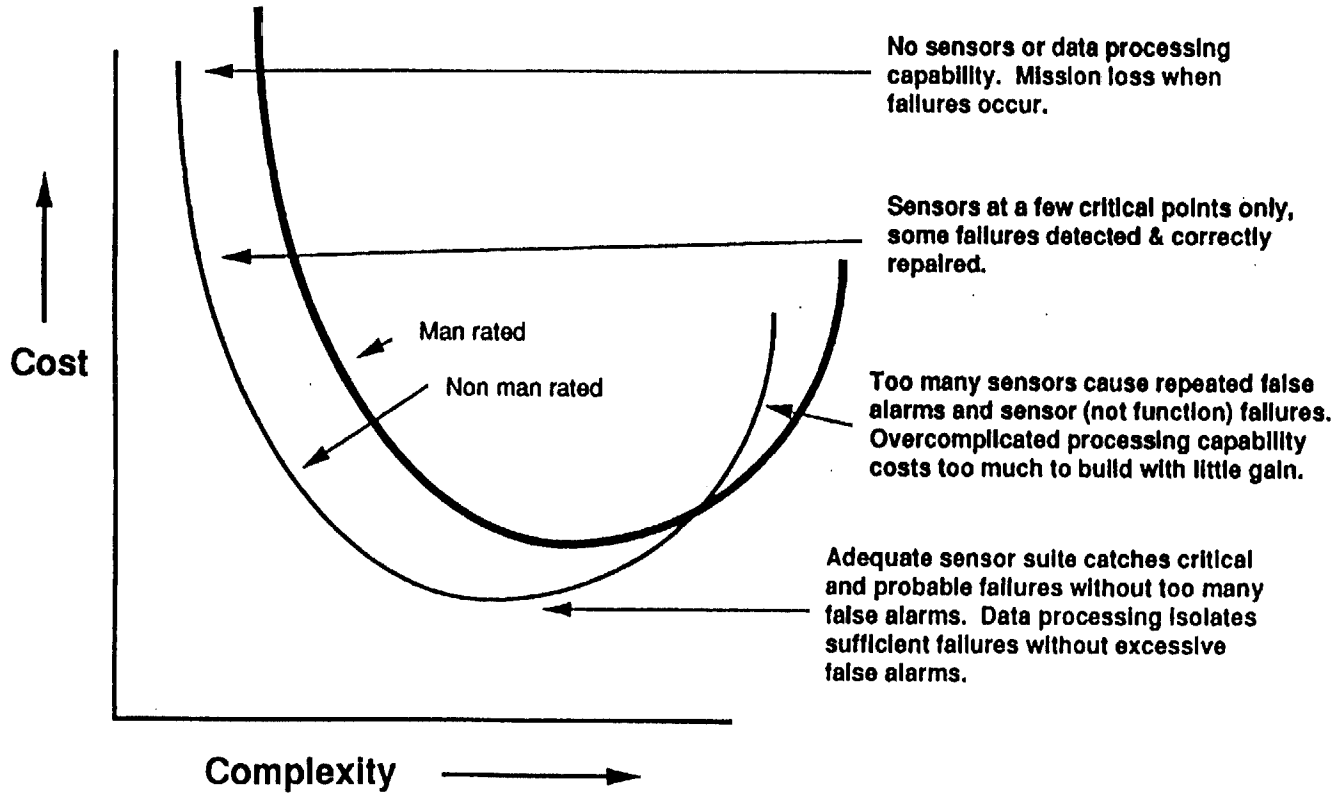


- **Mechanical flaw:** A leak of volatile hydrazine fuel may have caused an explosion when the spacecraft's tanks were pressurized.
- **Design flaw:** NASA engineers used technology that had been developed for operation in near-Earth orbit but was unsuitable for the more extreme conditions of interplanetary space.
- **Management flaw:** Project managers at the Jet Propulsion Laboratory did not exercise sufficient control over continuing changes in the spacecraft's design and its scientific instruments.

Source: NASA

Los Angeles Times

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



VHM COST OPTIMIZING CURVE

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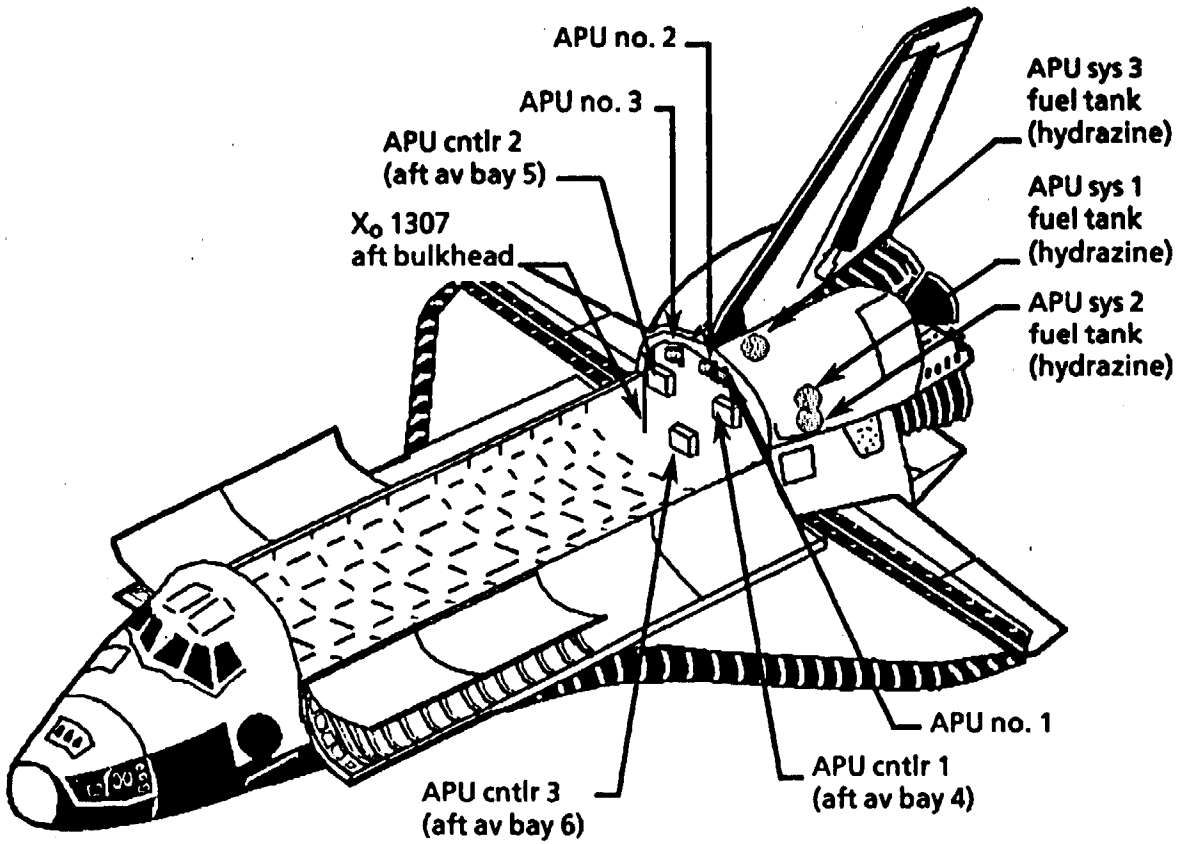
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



TARGET HMS - STS Auxiliary Power Unit Location

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INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

AUXILIARY POWER UNIT

- Provide power for the Orbiter hydraulic systems
  - liquid hydrazine -------> mechanical shaft power
- Hydraulic systems
  - actuate the Orbiter aerosurfaces
  - throttle and steer Orbiter main engines
  - deploy and steer landing gear
  - apply landing gear brakes
- Operation Cycle
  - t-5 min to OMS-1 burn
  - deorbit burn and entry to just before landing

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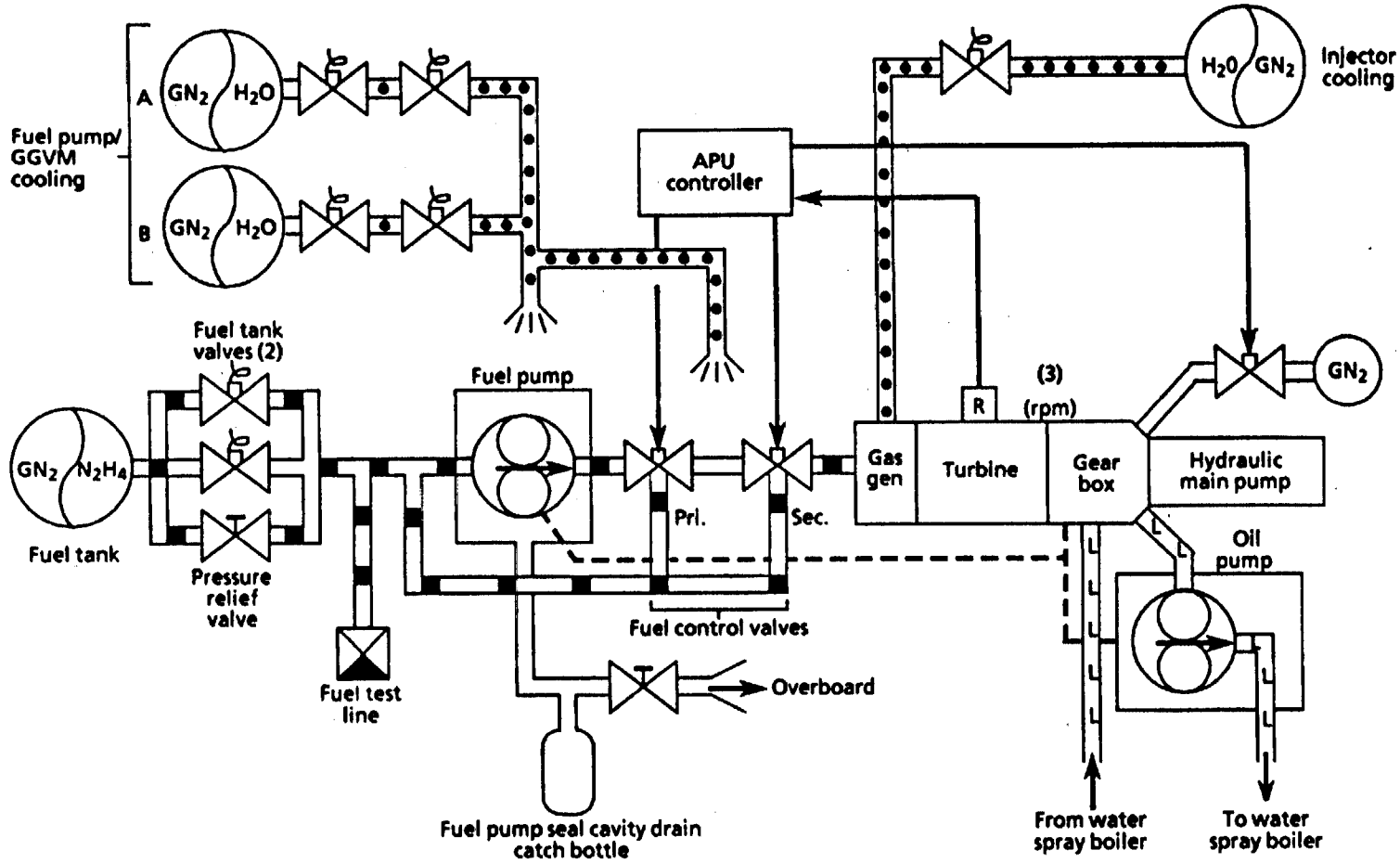
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

- **Monitoring fuel tank isolation, fuel control valves and electronic controller, e.g.,**
  - **valve open for > 2 min in orbit without fuel flow could detonate hyrazine near valve**
  - **leakage detection**
  - **high rmp pulser-type valves**

APU MONITORING AND DIAGNOSIS

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



TARGET HMS - STS Auxiliary Power Unit

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INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

TECHNOLOGY ISSUES

- Engineering alarm limits - critical thresholds which define the acceptable range of engineering values on any telemetry channel

  - determined manually: hardcopy ISOE data, design information on spacecraft, rules of thumb

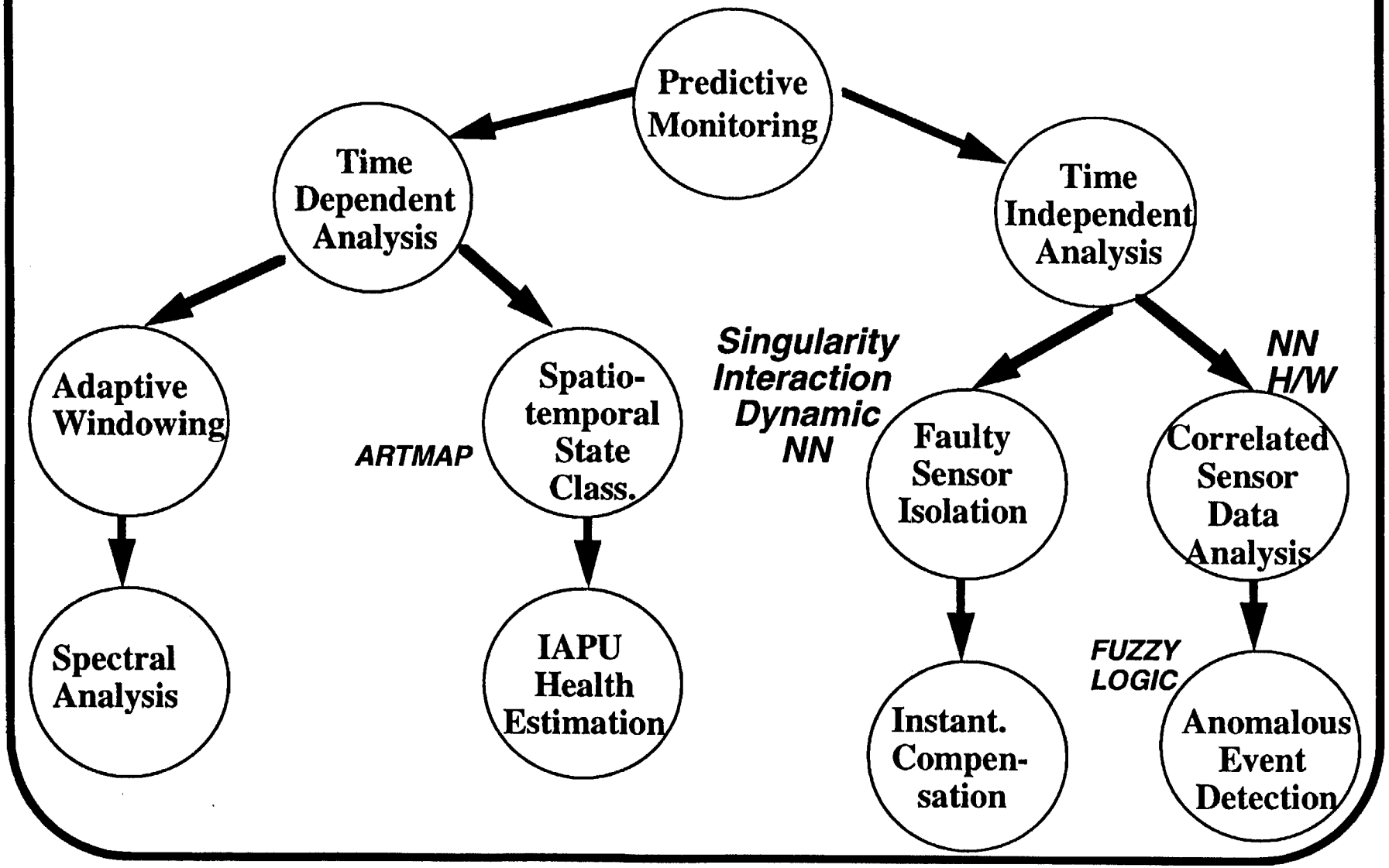
    - Overreliance on domain experts leading to wide thresholds creating a range of undetected anomalies
    - monitoring of individual sensors via redlining approach

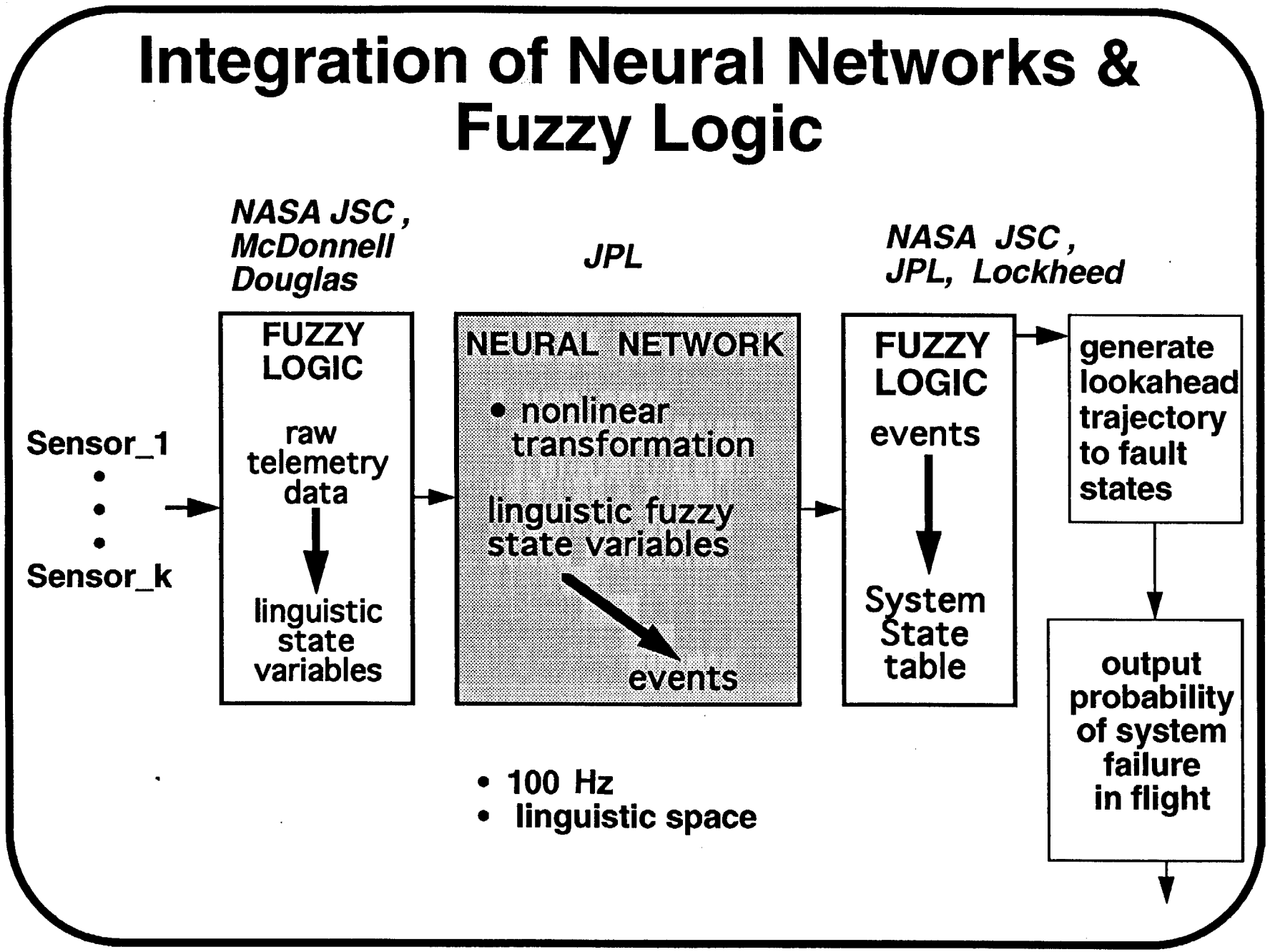
- Access only to snapshots of telemetry due to exploitation of low sensor acquisition rates. Further degradation due to noisy and incomplete data

- Specific diagnostics can be executed only if they were preconceived and preprogrammed

  - cannot currently correlate effects between multiple sensors in real-time
  - fault-detection to engine catastrophy time can be as short as 0.1 sec.

INTELLIGENT NEURO-FUZZY SYSTEM for STS APU Health Monitoring




Integration of Neural Networks & Fuzzy Logic
NASA JSC , McDonnell Douglas
JPL
NASA JSC , JPL, Lockheed
Sensor_1
Sensor_k
FUZZY LOGIC
raw telemetry data
linguistic state variables
NEURAL NETWORK
• nonlinear transformation
linguistic fuzzy state variables
events
FUZZY LOGIC
events
System State table
generate lookahead trajectory to fault states
output probability of system failure in flight
• 100 Hz
• linguistic space

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

STS / APU HEALTH MONITORING

- detection of all red line errors currently identified
- real-time correlation of data from multiple heterogeneous sensors
  - faster-than-real-time anomaly propagation to determine probability of failure
  - both with (using NN s/w) and without (using NN h/w) time-lags
- ease of augmenting expert-generated APU fault knowledge base without needing to redesign the system
- isolating failed sensors as against failed subsystem / system
  - reconstruct suspect information and minimize disruption of diagnostic process
- synergistic integration of fuzzy logic and neural networks for real-time diagnostic applications

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INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

STS / APU HEALTH MONITORING

- Startup & mode-switch phases difficult to monitor due to highly complex & nonlinear nature of IAPU dynamics

- reduced engine / test stand damage during test firings
  - typically damage 1 APU every 2 weeks

- facilitate post-test diagnostic process
  - tool for APU knowledge engineering

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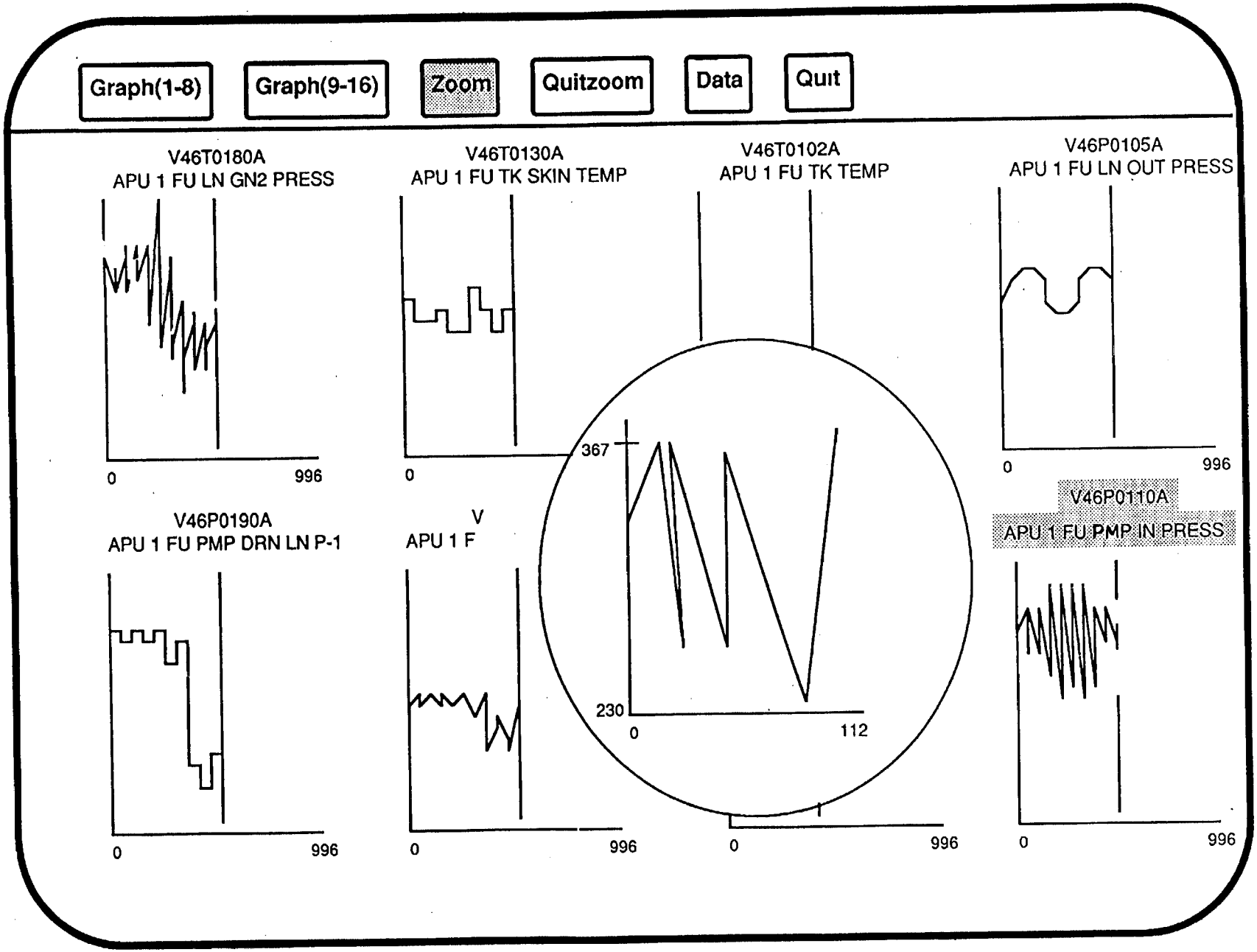
Graph(1-8)
Graph(9-16)
Zoom
Quitzoom
Data
Quit
V46T0180A
APU 1 FU LN GN2 PRESS
0
996
V46T0130A
APU 1 FU TK SKIN TEMP
0
V46T0102A
APU 1 FU TK TEMP
367
230
0
112
0
996
V46P0105A
APU 1 FU LN OUT PRESS
0
996
V46P0190A
APU 1 FU PMP DRN LN P-1
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996
V
APU 1 F
0
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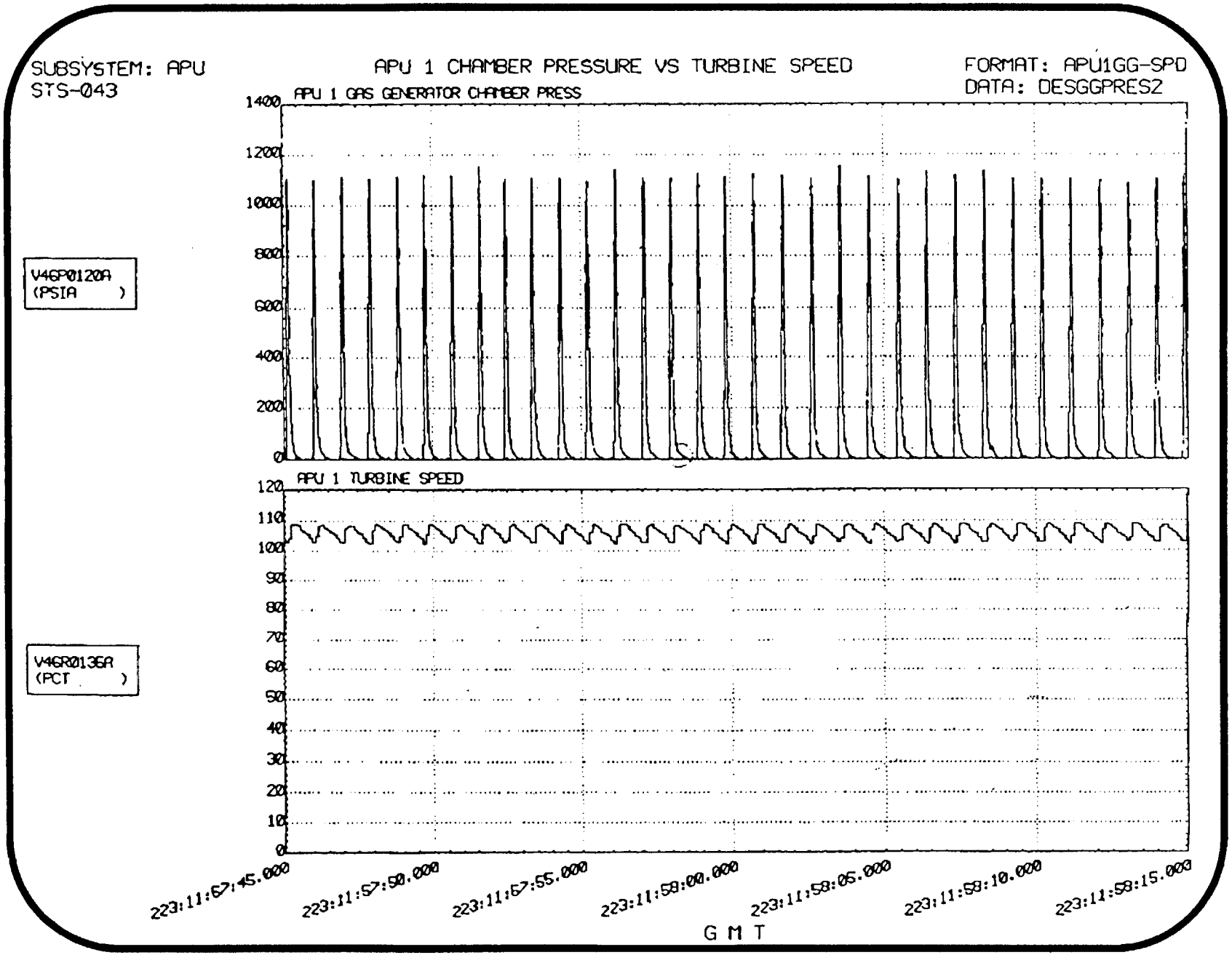
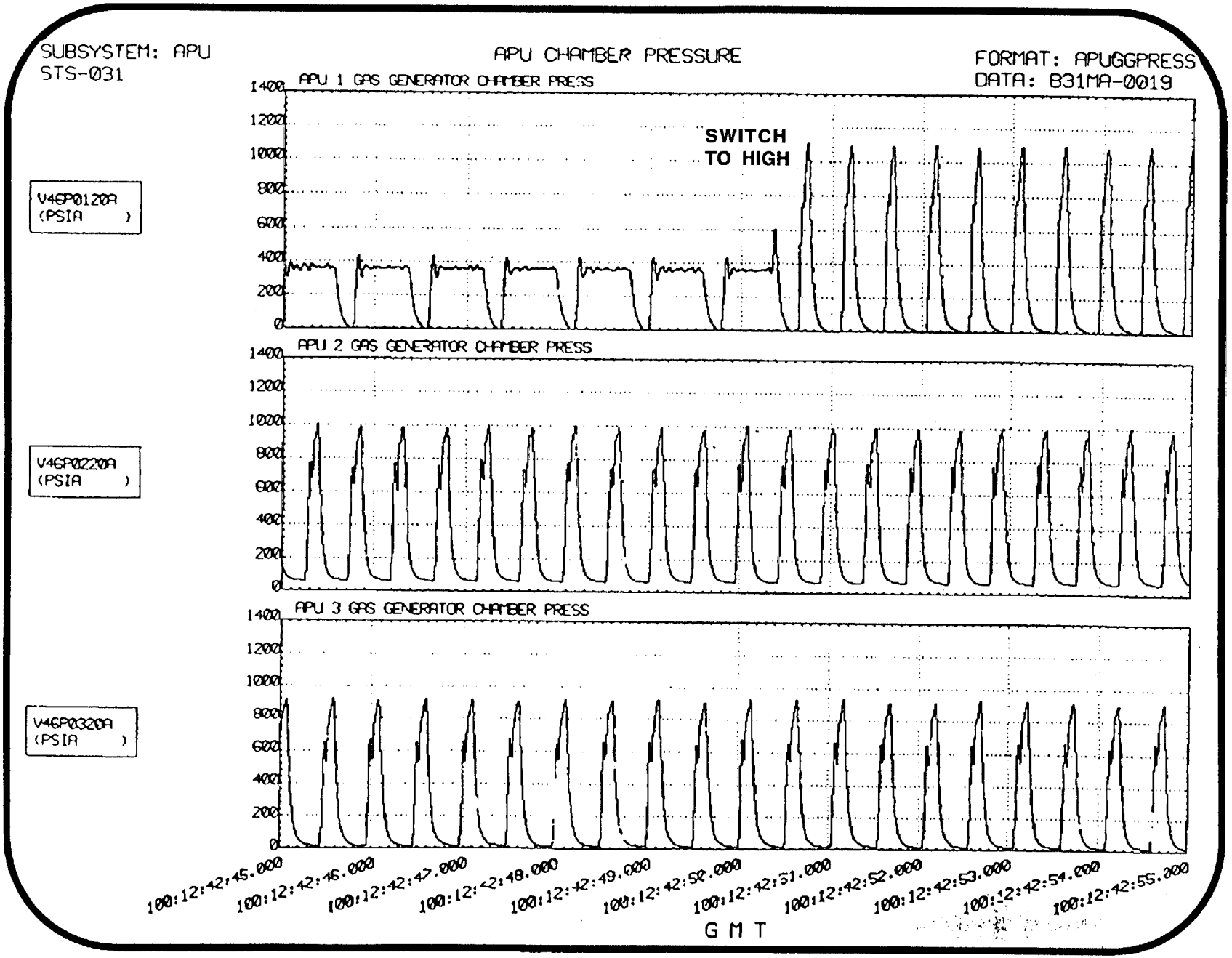
V46P0110A
APU 1 FU PMP IN PRESS
0
996


SUBSYSTEM: APU
STS-043
APU 1 CHAMBER PRESSURE VS TURBINE SPEED
FORMAT: APU1GG-SPD
DATA: DESGGPRES2
APU 1 GAS GENERATOR CHAMBER PRESS
1400
1200
1000
800
600
400
200
0
V46P0120A
(PSIA)
APU 1 TURBINE SPEED
120
110
100
90
80
70
60
50
40
30
20
10
0
V46R0136A
(PCT)
223:11:57:45.000
223:11:57:50.000
223:11:57:55.000
223:11:58:00.000
223:11:58:05.000
223:11:58:10.000
223:11:58:15.000
G M T


SUBSYSTEM: APU
STS-031
APU CHAMBER PRESSURE
FORMAT: APUGGPRESS
DATA: B31MA-0019
APU 1 GAS GENERATOR CHAMBER PRESS
SWITCH
TO HIGH
V46P0120A
(PSIA)
APU 2 GAS GENERATOR CHAMBER PRESS
V46P0220A
(PSIA)
APU 3 GAS GENERATOR CHAMBER PRESS
V46P0320A
(PSIA)
1400
1200
1000
800
600
400
200
0
100:12:42:45.000
100:12:42:46.000
100:12:42:47.000
100:12:42:48.000
100:12:42:49.000
100:12:42:50.000
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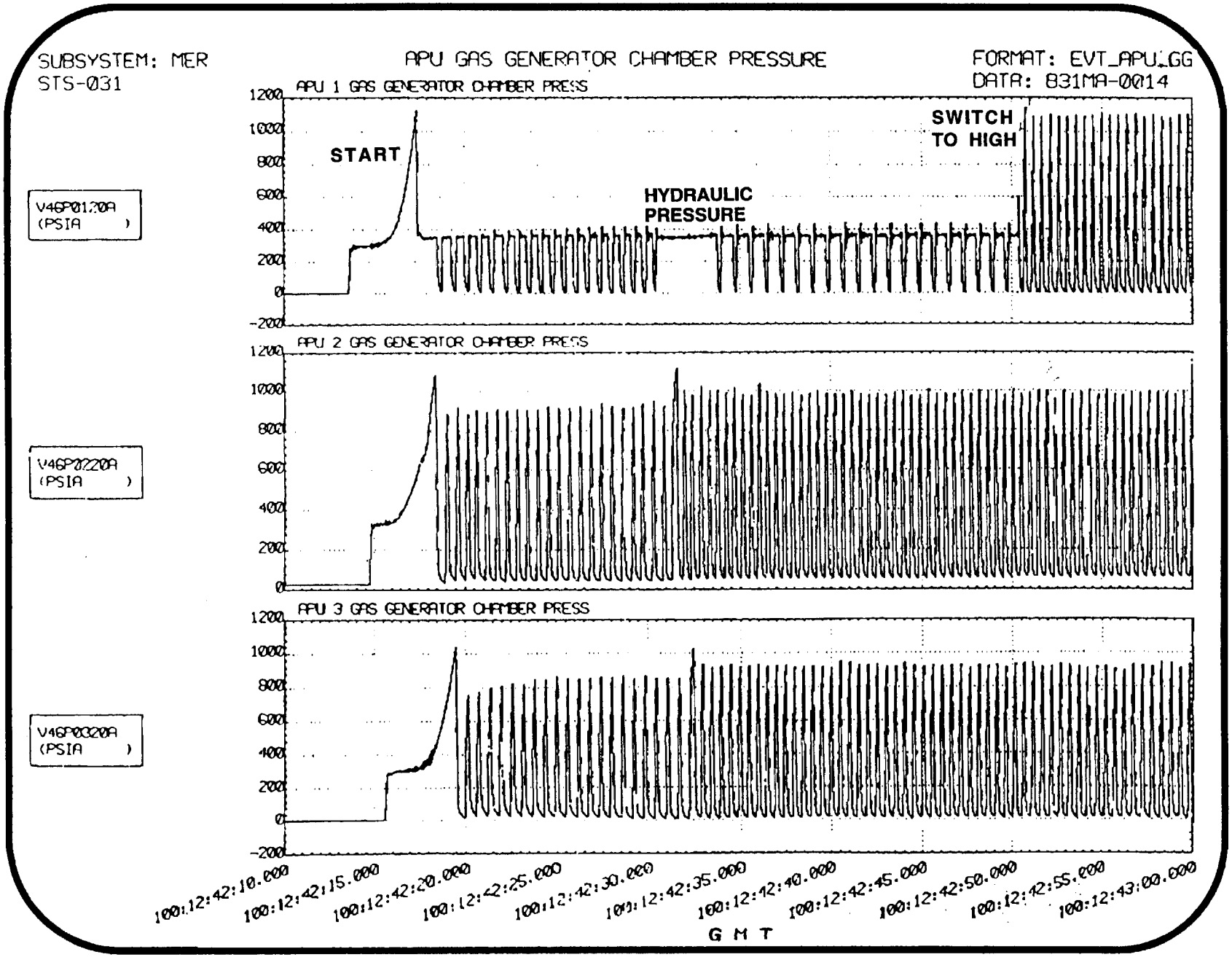
100:12:42:55.000
G M T


SUBSYSTEM: MER
STS-031
APU GAS GENERATOR CHAMBER PRESSURE
FORMAT: EVT_APU_GG
DATA: 831MA-0014
APU 1 GAS GENERATOR CHAMBER PRESS
APU 2 GAS GENERATOR CHAMBER PRESS
APU 3 GAS GENERATOR CHAMBER PRESS
START
HYDRAULIC PRESSURE
SWITCH TO HIGH
V46P01200A (PSIA)
V46P02200A (PSIA)
V46P03200A (PSIA)
1200
1000
800
600
400
200
0
-200
100:12:42:10.000
100:12:42:15.000
100:12:42:20.000
100:12:42:25.000
100:12:42:30.000
100:12:42:35.000
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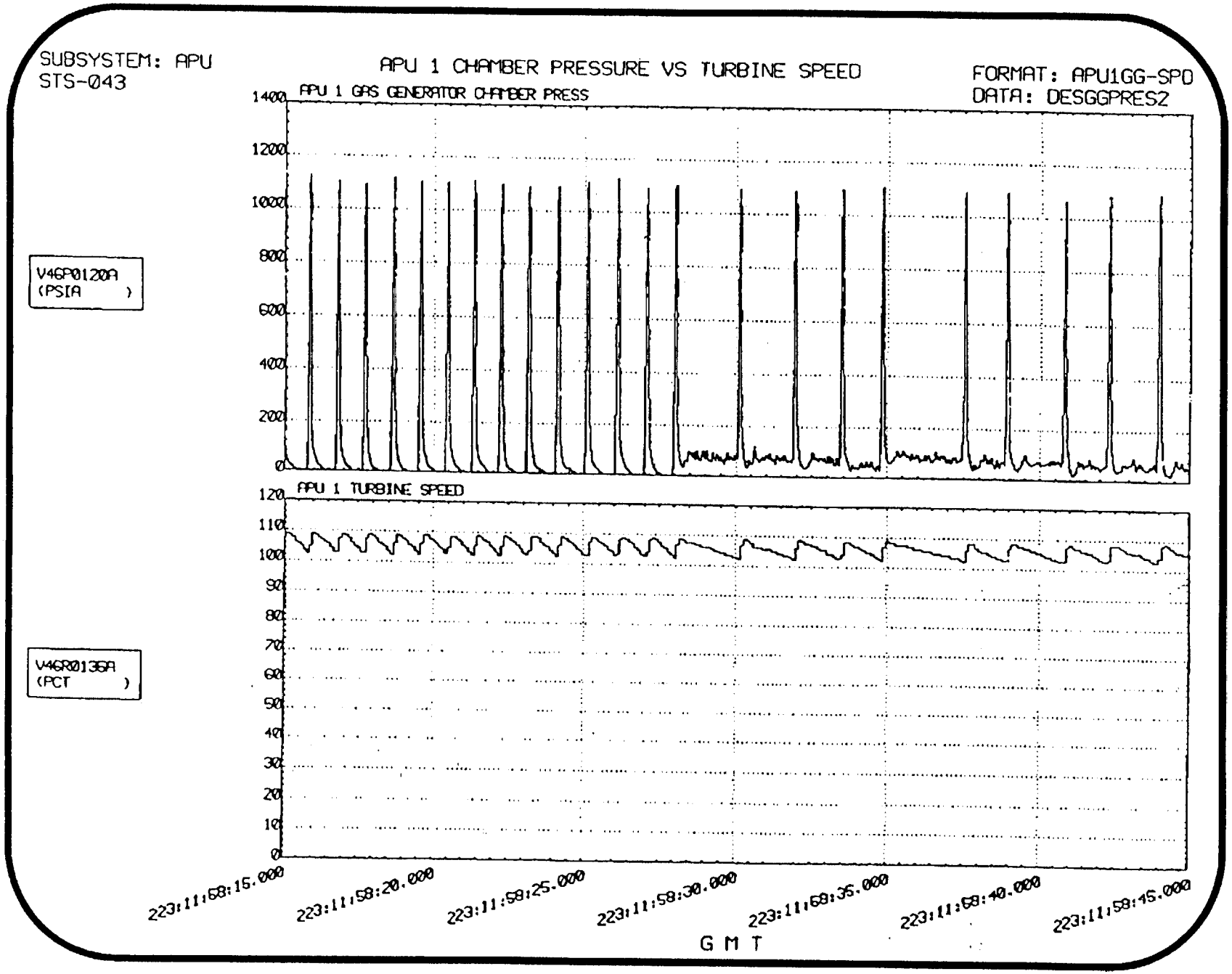
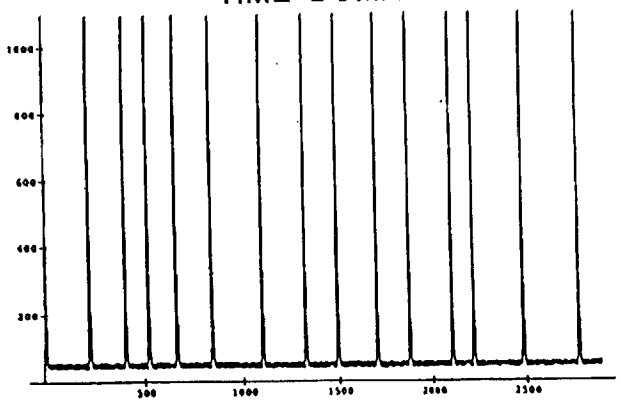
100:12:42:55.000
100:12:43:00.000
G M T


SUBSYSTEM: APU
STS-043
APU 1 CHAMBER PRESSURE VS TURBINE SPEED
FORMAT: APU1GG-SPD
DATA: DESGGPRES2
APU 1 GAS GENERATOR CHAMBER PRESS
V46P0120A
(PSIA)
APU 1 TURBINE SPEED
V46R0136A
(PCT)
223:11:58:15.000
223:11:58:20.000
223:11:58:25.000
223:11:58:30.000
223:11:58:35.000
223:11:58:40.000
223:11:58:45.000
G M T

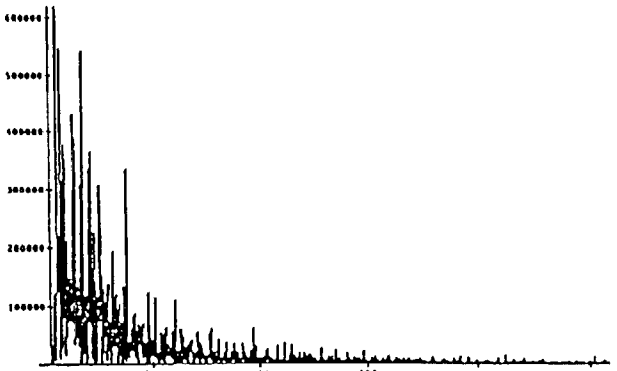
VHM SENSOR DATA WITH CHANGING FREQUENCY AND ADDITIONAL GROUND NOISE

TIME DOMAIN



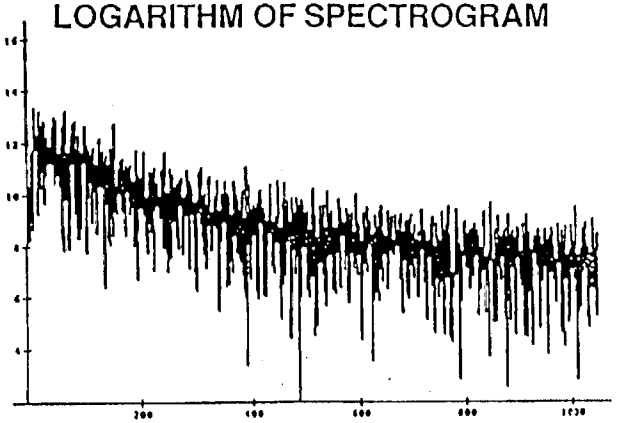
TIME

SPECTROGRAM



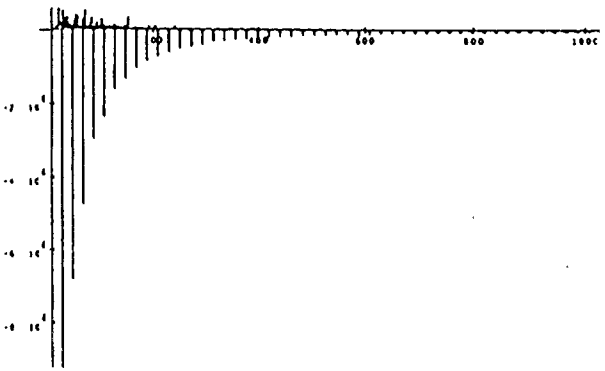
FREQUENCY

LOGARITHM OF SPECTROGRAM



FREQUENCY

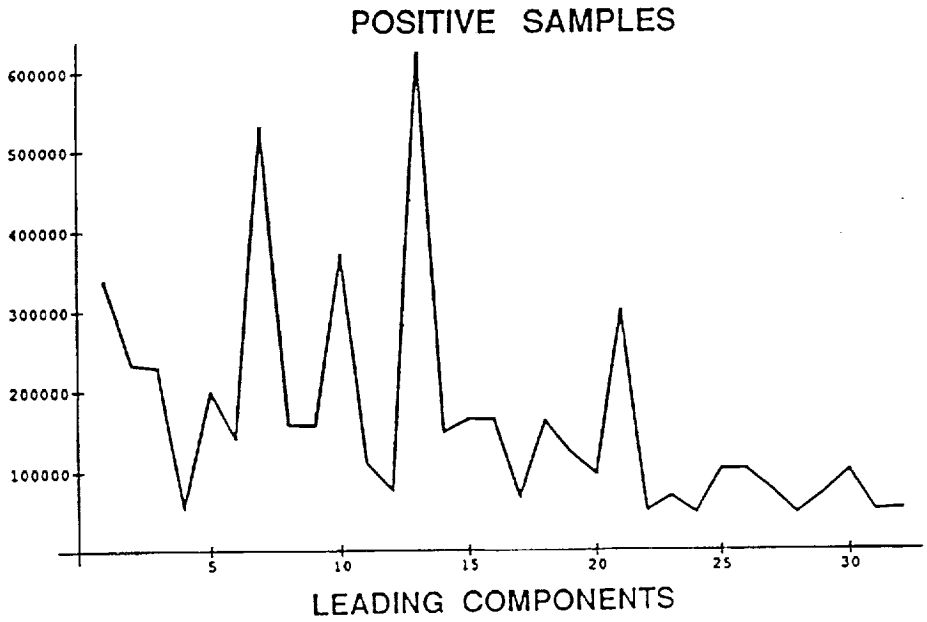
SPECTROGRAM DIFFERENCE

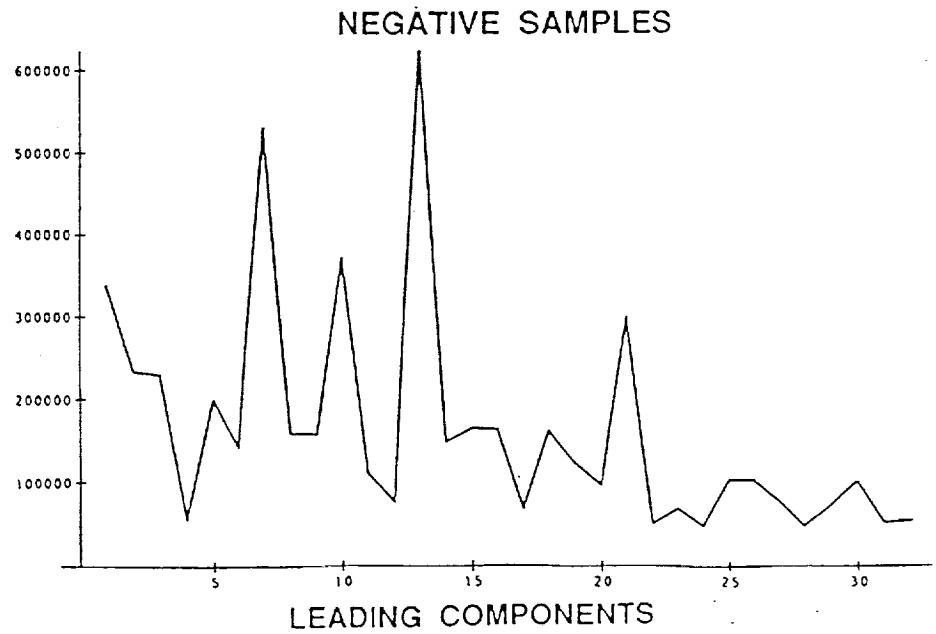


FREQUENCY

SAMPLED SPECTROGRAM DIFFERENCE

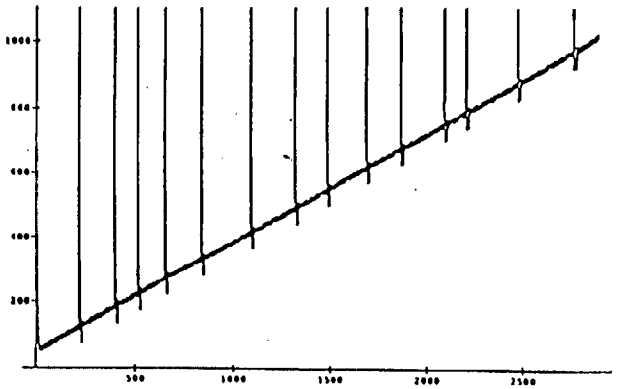
VHM SENSOR DATA WITH VARIATIONS IN FREQUENCY AND GROUND NOISE





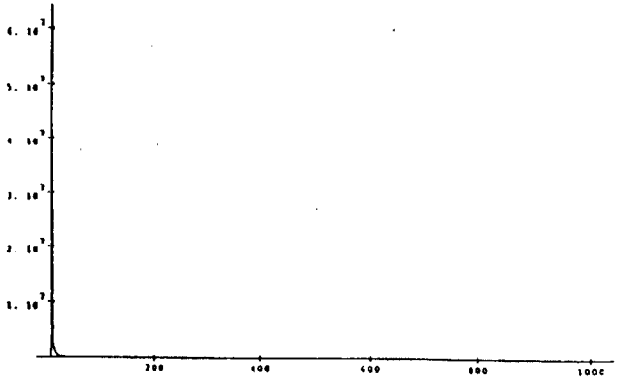
VHM SENSOR DATA WITH CHANGING FREQUENCY AND NOISE BUILDUP

TIME DOMAIN



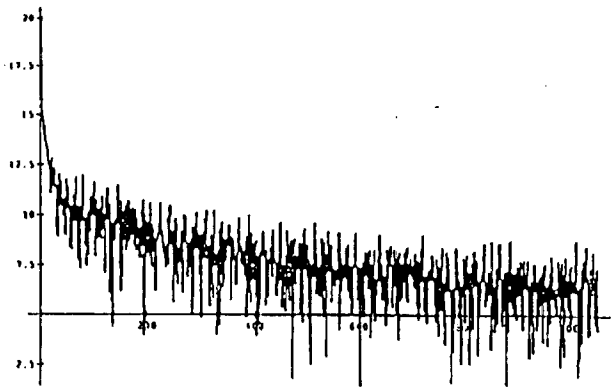
TIME

SPECTROGRAM



FREQUENCY

LOGARITHM OF SPECTROGRAM



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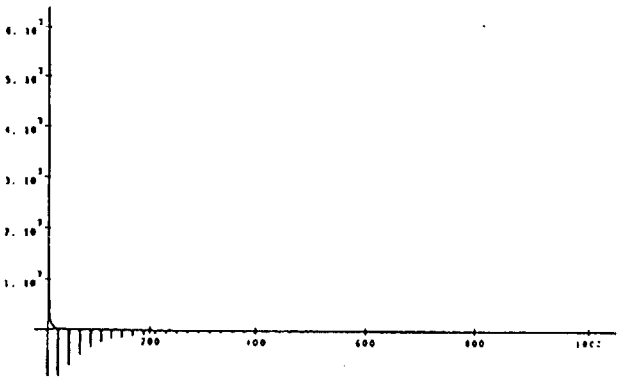
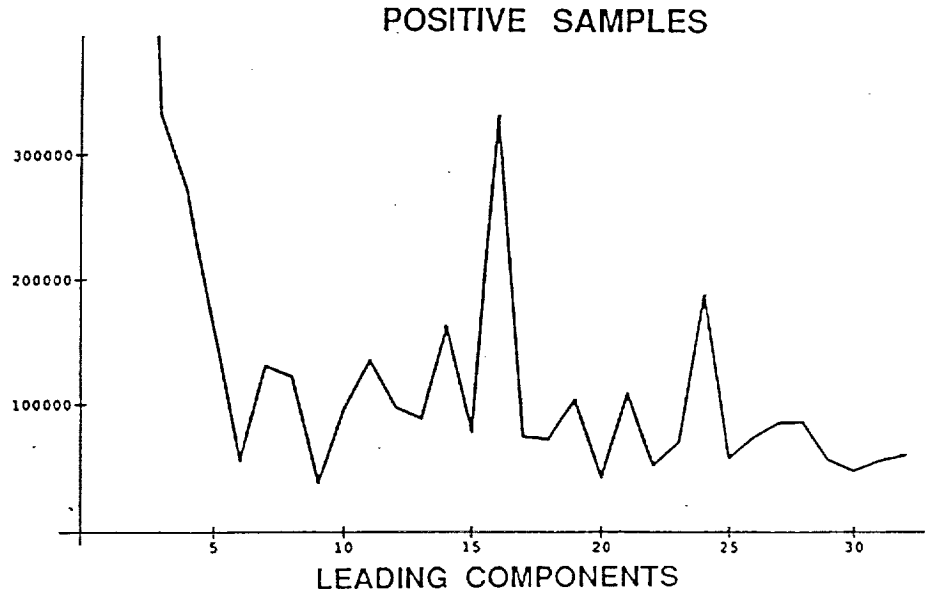
SPECTROGRAM DIFFERENCE

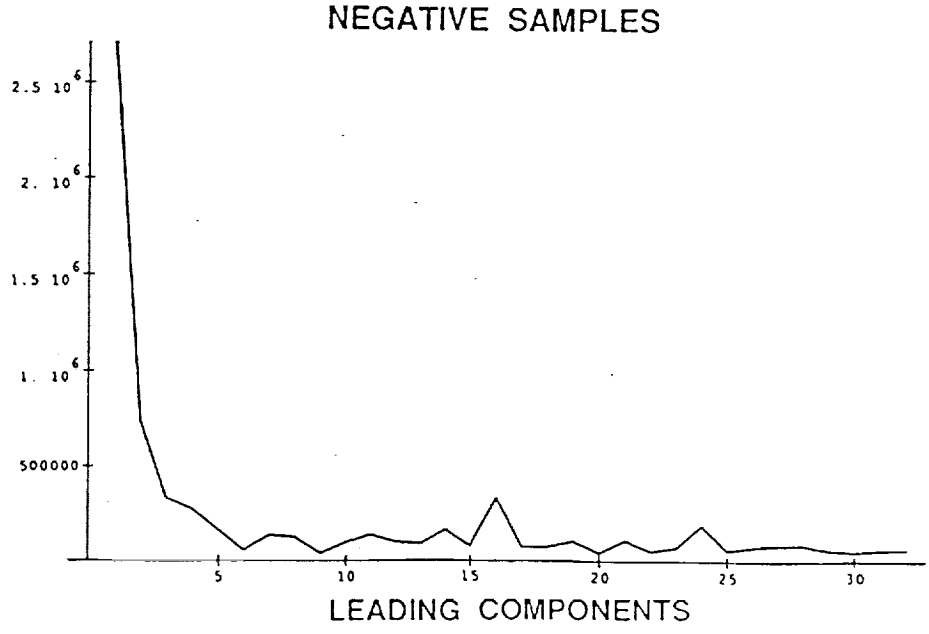


FREQUENCY

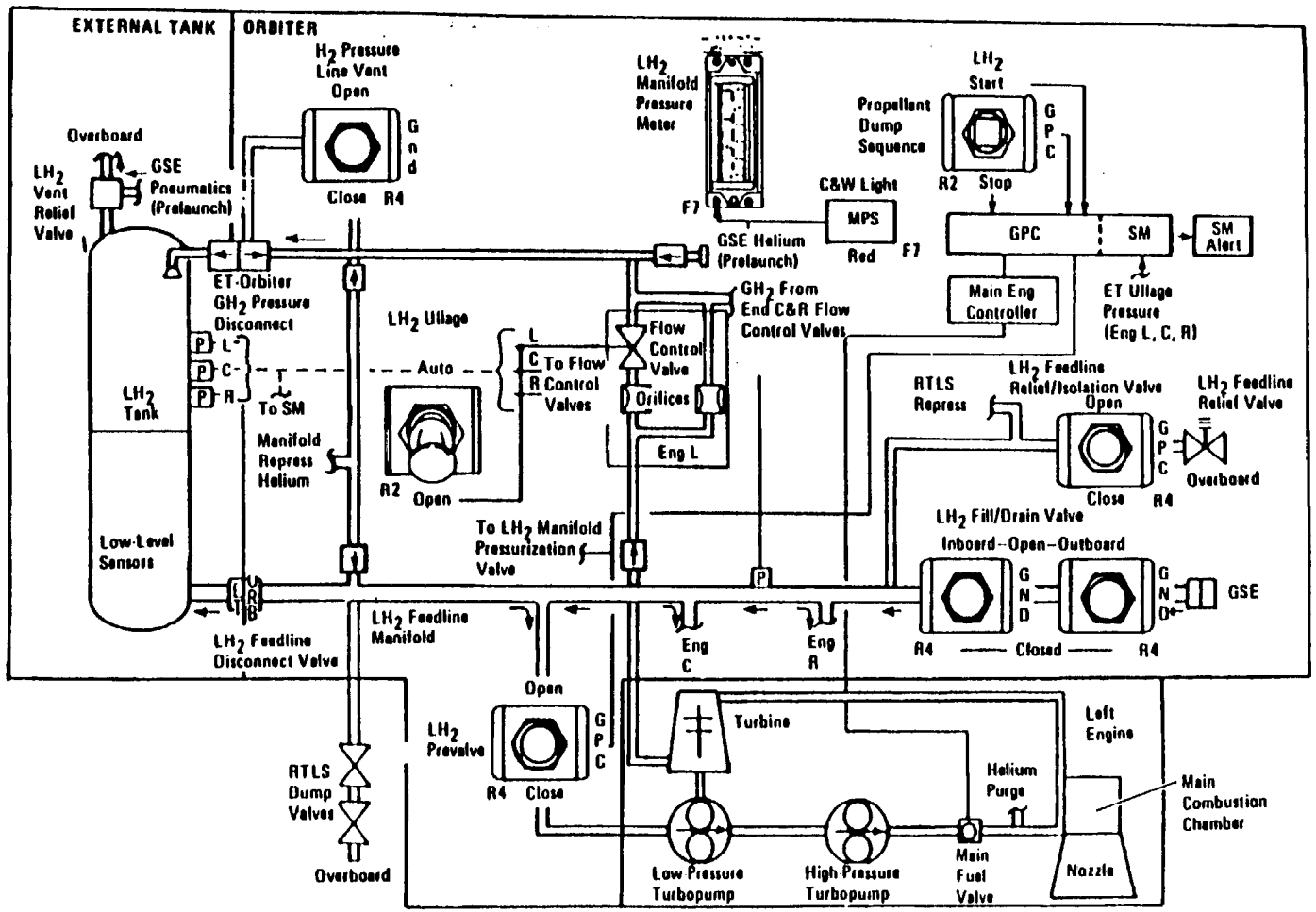
SAMPLED SPECTROGRAM DIFFERENCE

VHM SENSOR DATA WITH VARIATIONS IN FREQUENCY AND BUILDUP NOISE





INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



TARGET HMS - STS / MPS FUEL FLOW

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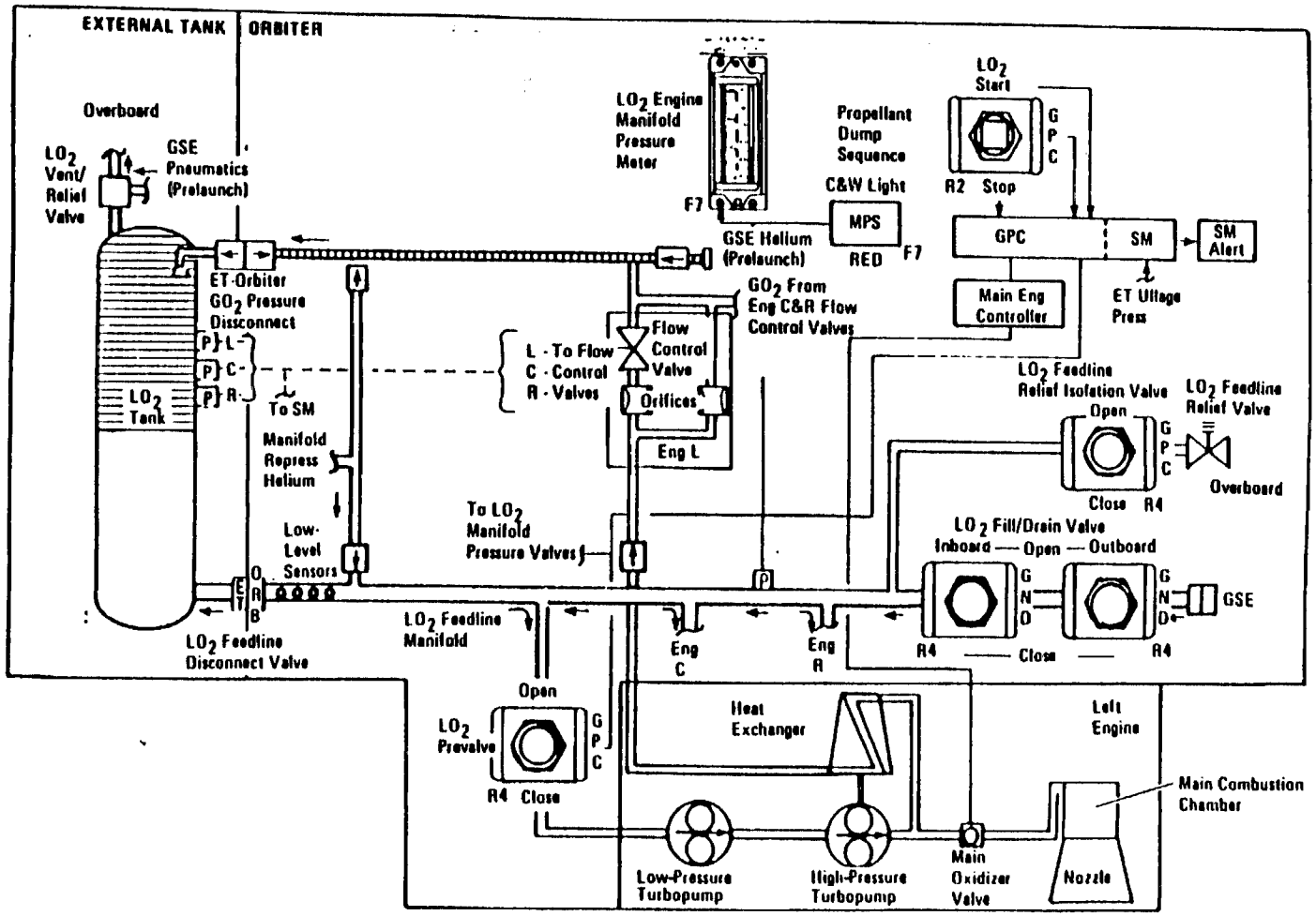
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



TARGET HMS - STS / MPS OXIDIZER FLOW

JPL